LBNE Tank Purge Manifold Pressure Drop Calculation

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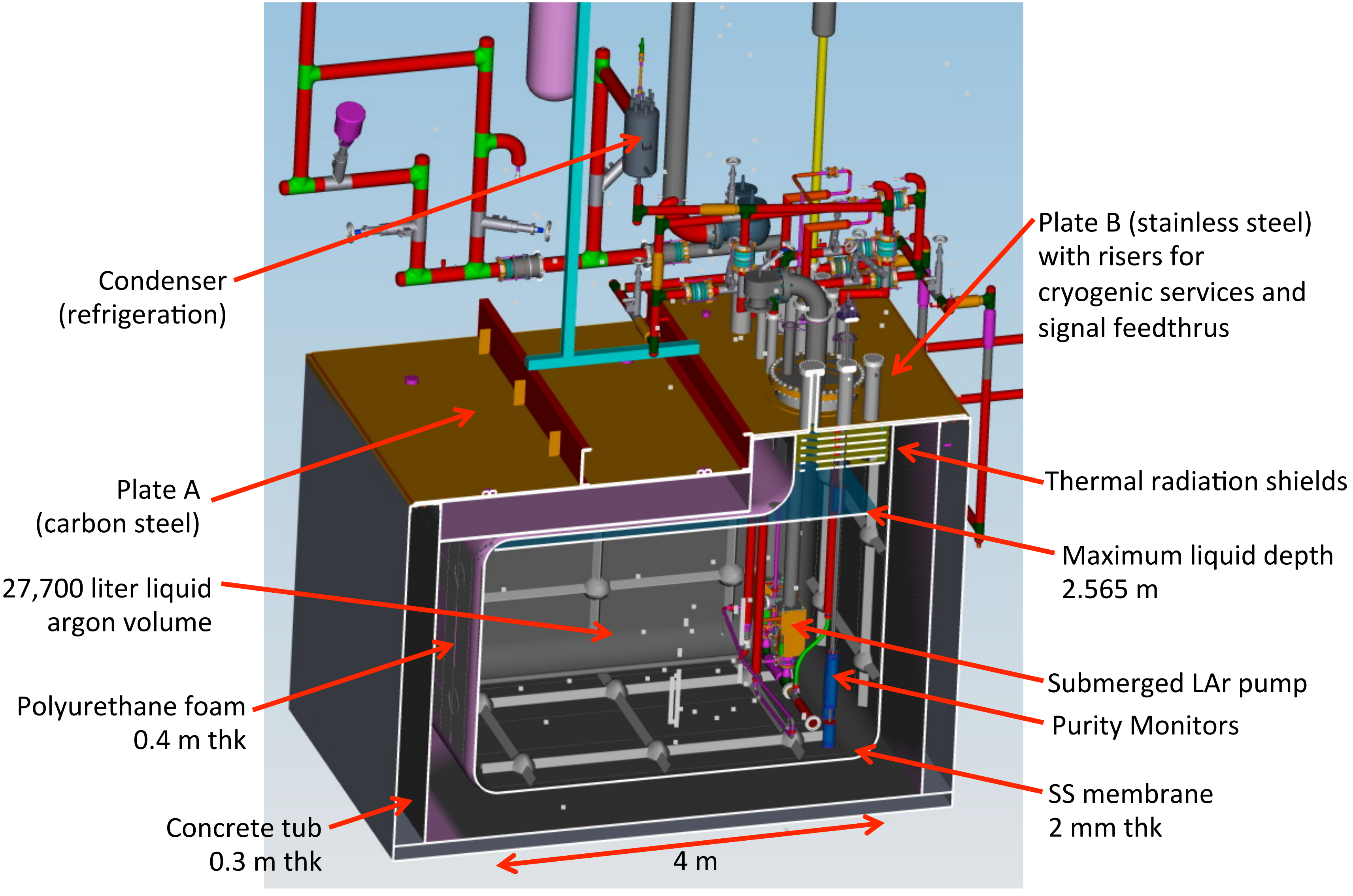
Background

- The Long-Baseline Neutrino Experiment (LBNE) wants to build a very large liquid Argon detector using membrane cryostat technology with passive foam insulation to do neutrino physics.
- 34 kton total Fiducial Mass at 4850L of Homestake Mine in Lead, SD, USA (~1.5 km underground). Phased approach: currently, at first 2 x 7,134 m^3 membrane cryostats, followed by 2 x ~15,100 m^3.
- Construction to start in the 2020 time frame and operations around 2024.
- Required LAr purity: less than **200 parts per trillion** (ppt) Oxygen equivalent contamination (electron lifetime greater than **1.4 ms**) to operate the neutrino detecting Time Projection Chambers (TPCs) inside the LAr.
- To ensure that membrane cryostat technology is suitable for this experiment, the LBNE 35 ton prototype has been built and operated, a ~28 m^3 membrane cryostat, the first and only membrane cryostat for scientific purpose and available to scientists.
- The 1^{st} run of this prototype achieved an electron lifetime of 2.5-3 ms.
- A 2^{nd} run will include a TPC along with some cryogenic upgrades

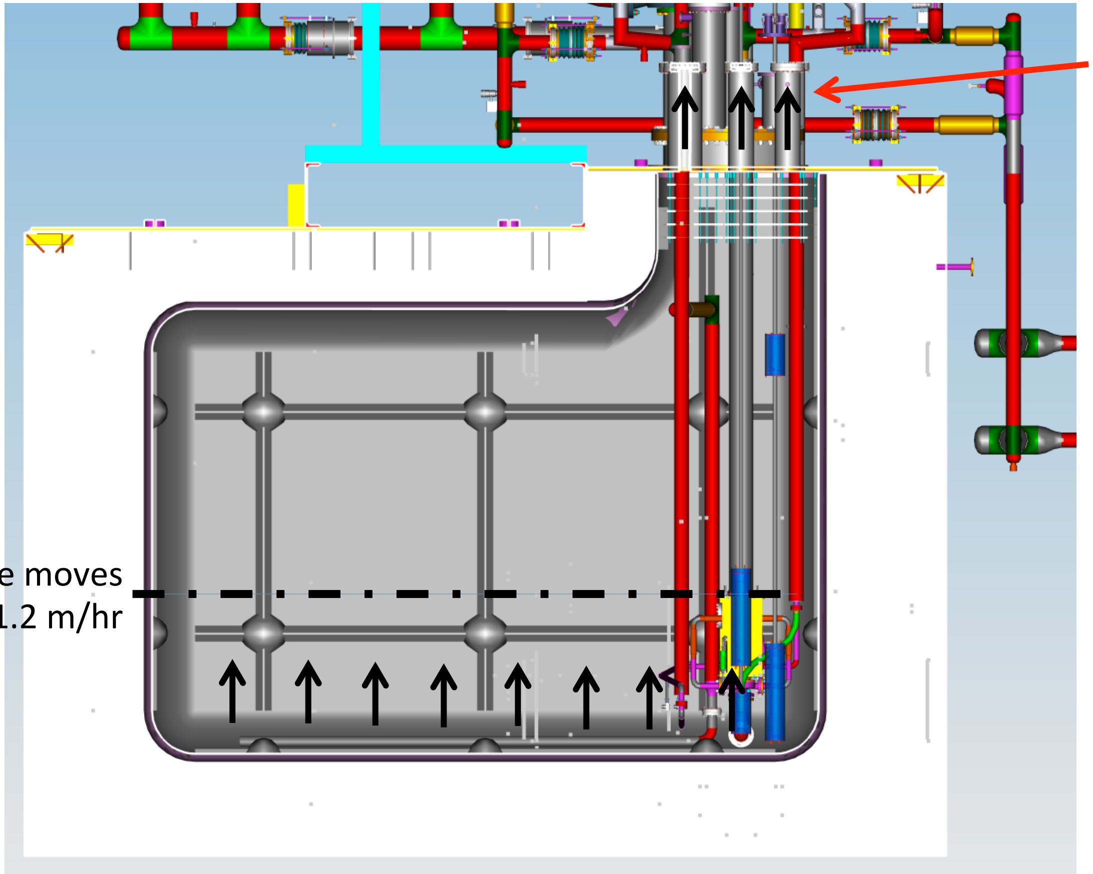
35T Cryostat Overview



Argon Piston Purge

- The primary contaminants are electronegative molecules such as oxygen and water
- The cryostat cannot be evacuated with a vacuum pump to remove air (traditional method)
- Argon gas is injected into the tank bottom to push the lighter air out the top
- This piston purge method was validated by the LAPD project and the 1st run of the LBNE 35T

Argon Piston Purge



Gas exits thru 19 separate feedthrus and vents to atmosphere

Argon-Air interface moves upward at 1.2 m/hr

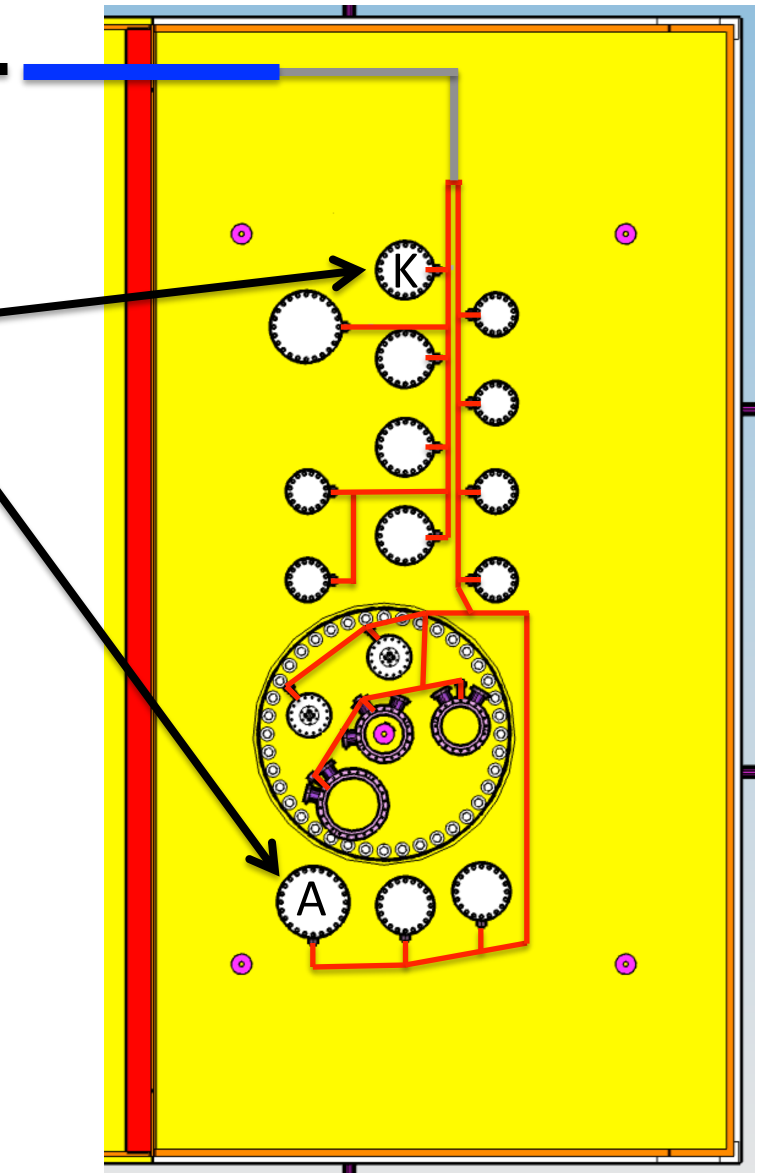
Room temperature argon gas injected at tank bottom thru 25 nozzles aimed downward just above floor - 210 SLPM total or 2.43 hours per volume change.

Motivation

- During the purge of the 1st run of the 35T the flow out of the risers was distributed unevenly
- Risers close to the vent had a greater flow rate than risers far from the vent
- Although this worked the 2nd 35T run will have larger sources of contamination and its desired to ensure all risers are purged effectively
- An orifice installed at the outlet of each riser can provide a "tuned" resistance which when matched with the tubing resistance results in the desired flow from each orifice

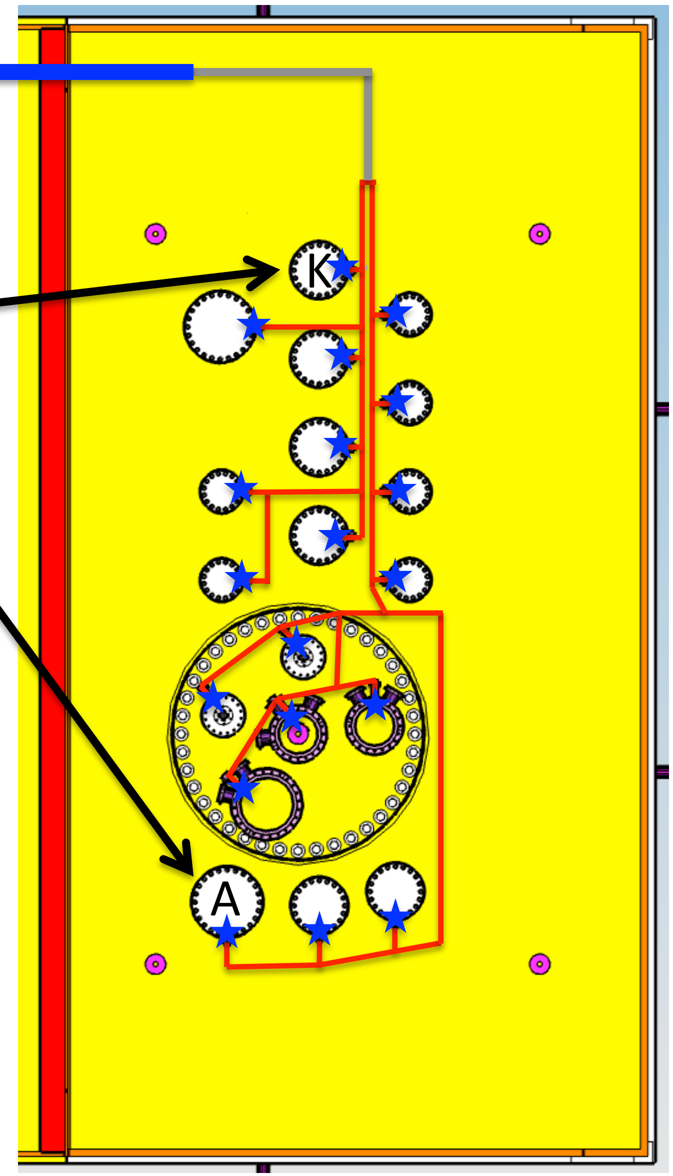
Purge vents outside

During 35T Run 1 flow out of riser K was greater than flow out of riser A



Purge vents outside

During 35T Run 2 flow out of each riser will be dictated by an orifice at each riser which will mitigate the variable resistance due to different tubing lengths



Pressure Drop using Air

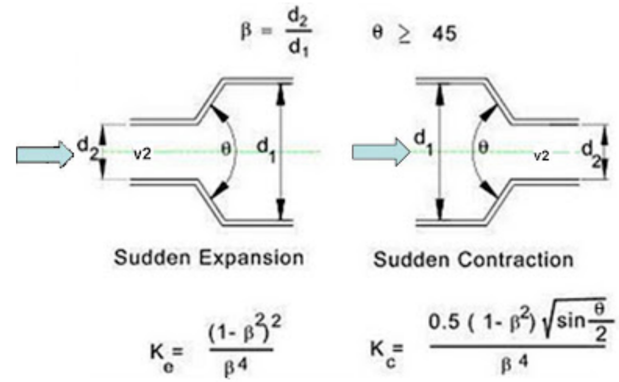
- Use of Crane 410 “bible”
- Pressure drop formula for fluid flow in pipes

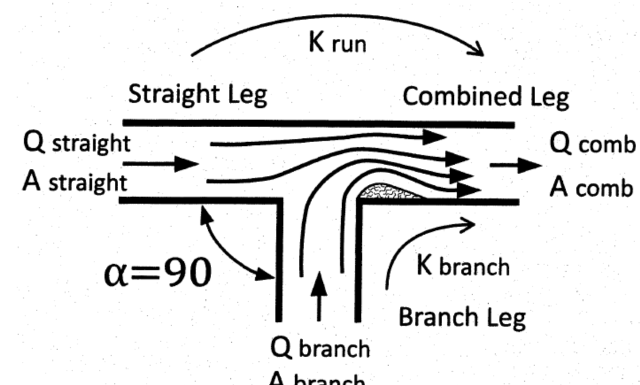
$$\Delta P = 3.62 K \rho q^2 / d^4$$

- Modification of the Darcy’s equation where *ΔP* is heavily dependent on resistant coefficient *K*, density of the fluid *ρ*, the nominal flow rate *q* and the internal diameter of the pipe *d*.

Resistance Coefficient-K

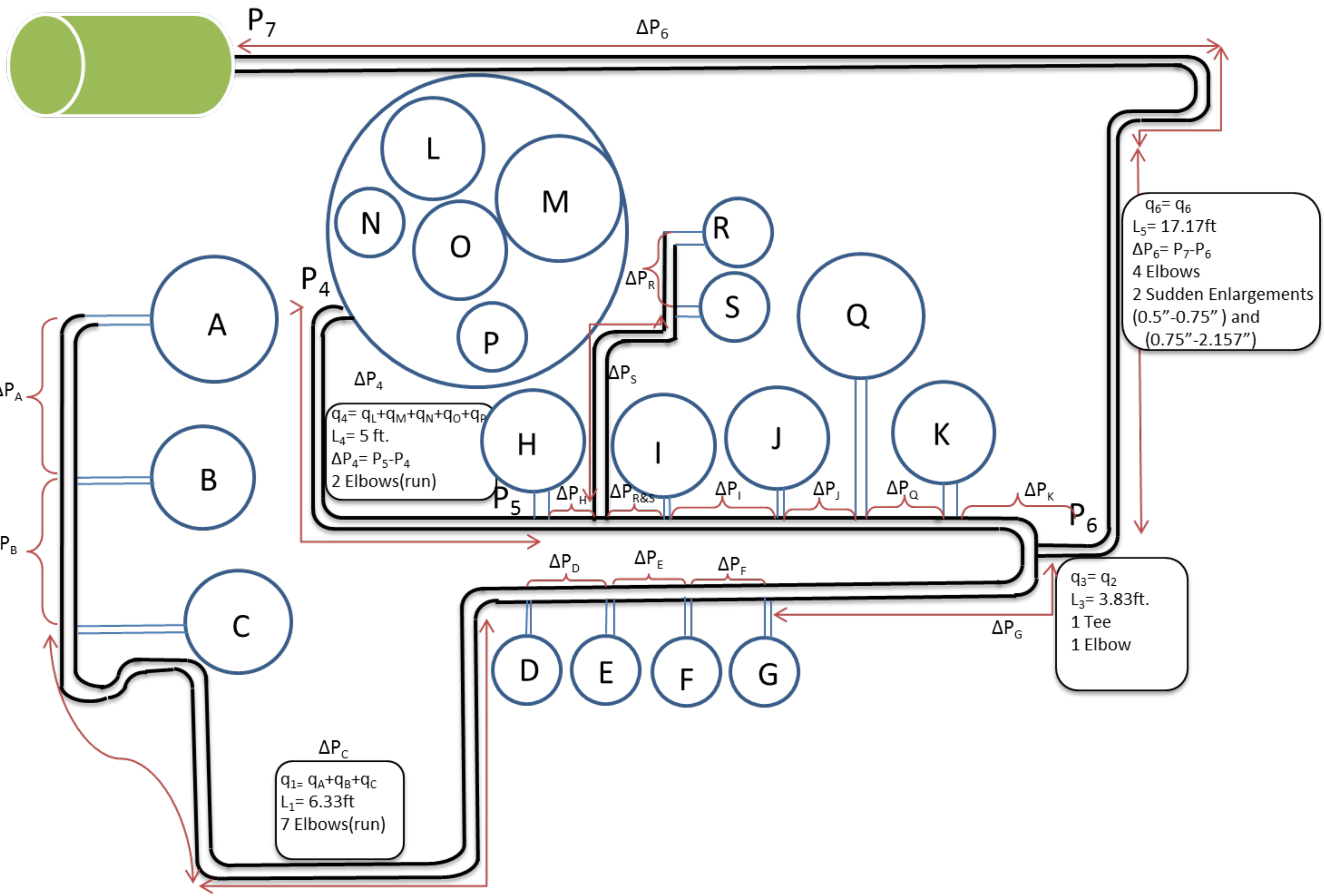
- Resistance to flow in pipes are;
  - sudden and gradual contraction and enlargement
    - ➢ Based on the ratio of the diameters and angle of convergence or divergence
  - Presence of elbows and tees
    - ➢ All the elbows are 90˚ standard elbows.
    - ➢ Resistance across 2 flow paths in a tee are through the run(straight path) and/or through the branch.
    - ➢ K_{run} and K_{branch} are dependent on the ratio of the single flow to the combined flow and the area ratio.
  - Friction due to the straight pipe.
    - ➢ Depends on friction factor, pipe length and pipe diameter
    - ➢ Friction factor *f* is obtained from moody chart based on flow's Reynolds number and pipe ID
    - ➢ Flow can either be laminar or turbulent (Re# 2300)
    - ➢ Pipe length is measured with a tape measure
- **Summation of all contributing resistance coefficients (K factors) between risers gives an equivalent resistance coefficient for calculating the pressure drop across a particular section**





Nominal Flow rate

- Total purge flow rate is fixed at 7.4 SCFM of Argon and divided among 19 risers
- Flow rate per riser is estimated based on ratio of individual CSA to the total CSA. Three riser internal diameters (3.87”, 5.87” and 7.87”)
- Flow is convergent as 2 or more streams combine to the next riser, hence flow is additive as the schematic shows



P7
ΔP6
L
M
N
O
P
R
S
Q
A
B
C
H
I
J
K
D
E
F
G
P4
P5
P6
ΔPA
ΔPB
ΔPC
ΔP4
ΔPR
ΔPS
ΔPH
ΔPR&S
ΔPI
ΔPJ
ΔPQ
ΔPK
ΔPD
ΔPE
ΔPF
ΔPG
q4= qL+qM+qN+qO+qP
L4= 5 ft.
ΔP4= P5-P4
2 Elbows(run)
q6= q6
L5= 17.17ft
ΔP6= P7-P6
4 Elbows
2 Sudden Enlargements
(0.5"-0.75") and
(0.75"-2.157")
q3= q2
L3= 3.83ft.
1 Tee
1 Elbow
q1= qA+qB+qC
L1= 6.33ft
7 Elbows(run)

Result

Riser Label	Actual flow rate (q)/ft^3/s	Re#	friction factor-f	K_B	K_{branch}	K_{run}	K_{elbow}	K_{eq}	ΔP_{Air} (Psi)	Initial Pressure (Psi)
	nominal based on area, summing risers	for half inch pipe	for half inch pipe						nominal	with 0.55 initial pressure
A	0.01596281	3182.368566	0.048	1.33966			0.81	2.14966	0.004343397	0.55
B	0.025864023	5156.288308	0.044	1.228021	0.15	0.4		1.778021	0.009431272	0.545656603
C	0.03288664	6556.327319	0.041	7.243371	-0.15	0.35	5.67	13.11337	0.112459088	0.536225331
D	0.035939063	7164.862744	0.04	1.149874	-0.5	0.15		0.799874	0.008192124	0.423766242
E	0.040713406	8116.682375	0.0395	1.135501	-0.55	0.13		0.715501	0.009404296	0.415574119
F	0.043765829	8725.217799	0.039	1.121128	-0.6	0.1		0.621128	0.009433922	0.406169823
G	0.046818252	9333.753223	0.0385	4.115406	-0.6	0.09	0.81	4.825427	0.083870133	0.396735901
L									P6 from G =	0.312865768
M										
N										
O										
P										
From tank to H	0.029696483	5920.333059	0.0395	5.512141			1.62	7.132141	0.049873646	0.55
H	0.036719101	7320.37207	0.038	0.54513	-0.2	0.25		0.59513	0.006362634	0.500126354
R	0.003052423	608.5354243	0.105170541	2.935265			0.81	3.745265	0.000276703	0.55
S	0.006104846	1217.070849	0.052585271	2.935265	0.4	0.52	1.62	5.475265	0.001618064	0.549723297
tee of R&S	0.042823947	8537.442918	0.0375	0.537957	-0.45	0.17		0.257957	0.003751128	0.49376372
I	0.049846565	9937.481929	0.0375	1.078007	-0.45	0.17		0.798007	0.015722387	0.490012592
J	0.056869182	11337.52094	0.037	0.530784	-0.5	0.15		0.180784	0.004636132	0.474290205
Q	0.069492464	13854.11635	0.036	0.516439	-0.2	0.25		0.566439	0.021690499	0.469654073
K	0.076515081	15254.15536	0.0355	1.813145	-0.55	0.13	0.81	2.613166	0.121311604	0.447963574
from p6 to Vent	0.123333333	16215.95198	0.035	11.06722	-0.9		3	14.31211	0.326579724	0.32665197
	$K_{contract}$ @ K & G =	0.210938081	$K_{enlarge}$ @ K &G=	0.199083					P6 from G =	0.312865768
	$K_{enlarge-1}$ @ P6 =	0.319278804							P6 from K =	0.32665197
	$K_{enlarge-1}$ @ P7=	0.825611812							P7 at Vent =	7.22462E-05

Initial pressure is reduced from 0.75 to 0.55 to ensure system consistency With reality

P6 from both branches of the flow maintain same pressure and the Outlet pressure is approx. zero showing Consistency with reality

Pressure Drop with Argon

- Using volumetric flow rate of air to size the orifices.
- We substitute for argon properties to obtain the pressure drop after orifice is size is set

Riser Label	ARGON→→→→	Re#	friction factor-f	K_B	K_{branch}	K_{run}	K_{elbow}	K_{eq}	ΔP_{Air} (Psi)	Initial Pressure (Psi)
		for half inch pipe	for half inch pipe						nominal	with 0.8 initial pressure
A		4098.296679	0.044	1.228021			0.81	2.038021	0.006123987	0.8
B		6640.336848	0.04	1.116383	0.15	0.4		1.666383	0.0131454	0.793876013
C		8443.325757	0.038	6.713369	-0.15	0.35	5.67	12.58337	0.160488088	0.780730612
D		9227.005792	0.0375	1.078007	-0.5	0.15		0.728007	0.011088584	0.620242525
E		10452.77181	0.037	1.063634	-0.55	0.13		0.643634	0.012581157	0.609153941
F		11236.45184	0.0365	1.04926	-0.6	0.1		0.54926	0.012406677	0.596572783
G		12020.13188	0.036	3.848172	-0.6	0.09	0.81	4.558193	0.117822969	0.584166107
L									P6 from G =	0.466343138
M										
N										
O										
P										
From tank to H		7624.283867	0.039	5.442367			1.62	7.062367	0.073445835	0.8
H		9427.272776	0.0375	0.537957	-0.2	0.25		0.587957	0.009348383	0.726554165
R		783.6800348	0.081665982	2.279263			0.81	3.089263	0.000339431	0.8
S		1567.36007	0.040832991	2.279263	0.4	0.52	1.62	4.819263	0.002118054	0.799660569
tee of R&S		10994.63285	0.037	0.530784	-0.45	0.17		0.250784	0.005423511	0.717205782
I		12797.62175	0.036	1.034887	-0.45	0.17		0.754887	0.022118683	0.711782271
J		14600.61066	0.0355	0.509266	-0.5	0.15		0.159266	0.006074127	0.689663588
Q		17841.51579	0.035	0.502093	-0.2	0.25		0.552093	0.03144088	0.683589461
K		19644.5047	0.034	1.736534	-0.55	0.13	0.81	2.536555	0.175123804	0.652148581
from p6 to Vent		20883.11921	0.034	10.75101	-0.9		3	13.9959	0.474954695	0.477024777
									P6 from G =	0.466343138
									P6 from K =	0.477024777
									P7 at Vent =	0.002070082

Starting pressure is higher than air

P6 equal from
Both ends and zero
outlet pressure at P7

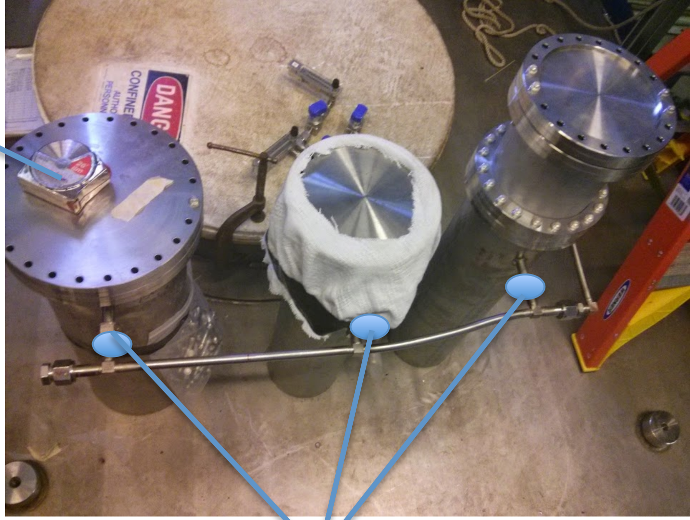
Sizing the Orifice

- Orifice functions as a flow meter
- Fluid flow through orifice is expressed by

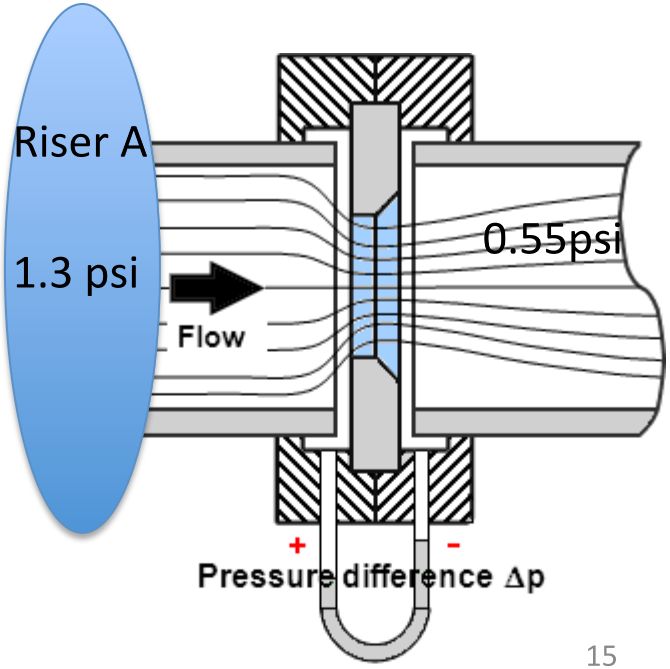
$$q = YCA\sqrt{2g(144)\Delta P/\rho}$$

  - Where Y is the expansion factor, C is the flow coefficient and A is the CSA
  - 0.75 psi pressure drop is assumed across the first orifice at A and each riser with initial pressure of 1.3 Psi
  - The required orifice diameter is calculated based on the desired riser flow and the pressure difference between the tank and the manifold position.

Riser A



Orifice location



Conclusion

- The pressure drop model obtained from analysis and calculation during the purge of air and argon out of the LBNE 35T tank is consistent with reality
- The tank purge operating pressure for air and argon is 1.3 psig and 1.55 psig respectively which is comfortably less than the maximum allowable tank pressure of 3 psig.
- Also the model allows for easy and accurate adjustment of the tank pressure, orifice sizes as well as tank gas should the need arise.

References

Flow of Fluids through Valves Fittings and Pipes: Technical Paper 410m. S.l.: Crane Valves, 1991. Print.

Personal communications with Terry Tope

LBNE Fermilab Website

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THANK YOU FOR LISTENING
BUT WAIT THERE'S MORE!

Questions